

APPLICATION
FOR
UNITED STATES LETTERS PATENT

TITLE: CALIBRATION FOR OPTICAL FILTER

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Express Mail Label No. EV399292251US

January 23, 2004
Date of Deposit

CALIBRATION FOR OPTICAL FILTER

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application serial no. 10/243,165, filed September 11, 2002, which is a divisional of U.S. application serial no. 09/778,242, filed February 6, 2001, which claims the benefit of U.S. provisional application serial no. 60/181,525, filed February 10, 2000.

BACKGROUND

Different kinds of optical filters are known. Optical filters can be formed by coating a blank to form an optical filter which has different characteristics in different locations of the filter.

Examples of such filters are found in U.S. Patent No. 5,426,576. In these optical filters, the amount of color saturation may vary based on the distance along a gradient axis. The gradient axis can be a linear gradient axis, or a circumferential gradient axis, in this patent. Also, two filters can be used together to form a cross fader.

Different kinds of coated optical filters are also known. In general, these coated optical filters may have characteristics that vary based on the amount of the coating.

SUMMARY

The present application teaches a system which enables consistent color from each of a plurality of luminaires, each of which use a coated optical filter.

According to the present application, a special technique of calibration is described for an optical filter which has characteristics that vary based a parameter of the optical filter, e.g. color that changes along a gradient axis.

BRIEF DESCRIPTION OF THE DRAWINGS

These and other aspects will now be described in detail, with reference to the accompanying drawings, wherein:

Figure 1 shows a block diagram of the luminaire system;

Figure 2 shows a flow diagram of forming the filters;

Figure 3 shows a diagram of rotation compensation for the filter characterization.

DETAILED DESCRIPTION

Figure 1 shows a system in which a light transmission device 90 including a lamp 10 and reflector 11 is caused to transmit light along an optical axis 12. Two color filters 14 and 15 are placed along the optical axis. Each of the color filters, such as 14, may include an alignment mark 125. The

alignment mark 125 may include, for example, a physical hole in the filter. The alignment mark allows the system to determine a set point in the filter, for example the beginning of a certain color spectrum. The filters are coated with a varying amount of filtering medium, so that different areas on the filter produce a different color effect.

The two color filters can be moved relative to one another by the motors SM1 and SM2. By moving the color filters, the degree of saturation changes, and hence the color output changes. The motors SM1 and SM2 are controlled by a controller 100. The controller 100 operates according to a prestored program which may be stored in its memory 110.

According to the present system, each luminaire 99 should, on cue, produce the same color. This is done according to the present system by calibrating each of the filters 14, 15 in each luminaire 99 based on a reference standard. The calibration allows each luminaire to know an exact position of the filter that produces a specific color effect even if there are positional and/or color differences between the filters.

The system used herein may use a parametric color filter of the type described in U.S. Patent No. 5,426,576. Alternatively, any other kind of filter that has characteristics that vary according to a parameter of the filter, here a distance along a gradient axis, may be compensated using this system.

No two filters, in general, will be exactly the same. One technique used herein is to provide tight tolerances on certain aspects of the filter, and allow other aspects of the filter to be corrected by the calibration process. For example, spectral form, radially, start and end points may be tightly controlled. Other parameters such as relationship of the aperture hole to the coating edge, and linearity, may be more loosely controlled.

In addition to manufacturing differences in the filter itself, another source of errors in the filters may involve the combining of the filters 14, 15 with the hub that carries the filters shown as 121. In this embodiment, the hub includes a magnet 123 which is used to set a 'home' position of the filter relative to the optical axis 12 of the luminaire 99. In assembling the filters, a jig may align the center of the magnet 123 to the aperture hole in the filter. Errors in this assembly may arise, for example due to the physics of the way the manufacturing jig mounts the devices. The jig can not have too tight a fit in the aperture hole, because of the fragile nature of certain filters. For example, certain filters may be manufactured from Vycor (TM); a form of fused silica manufactured by Corning, Inc. Other sources of manufacture and assembly errors may be also be expected. In general, this may provide an error up to plus or minus 0.5 degrees.

The calibration operation is shown in Figure 2. This calibration operation may be carried out on a test jig for example. At 200, the parametric color filter is assembled using the jig. As described above, this is done using the best possible accuracy, although it should be understood that certain errors will inevitably occur.

In order to calibrate each filter, the filters must first be characterized. 210 shows scanning the coated area of the filter at intervals. The scanning can use an ultraviolet or visible spectrophotometer to scan the filter at regular intervals. The intervals between scans should remain constant for each filter so that the characteristics of each filter are consistent from filter to filter. Each scan produces a set of data in the form of transmittance as a function of wavelength. The scan is then analyzed to find the location where the value cuts on to 50 percent. The color at any point in the filter can then be represented as a single value.

This creates a map of points showing the optical characteristics of the filter as a function of the position on the filter. The maps can use a specified point in the slope curve of the data. Here, that specified point is selected to be 50 percent of the cut on value. Other slope points could also be selected. The map essentially becomes a table of 50 percent cut on points and a position where those 50 percent cut on

points occur. This may be stored, for example, as a 16-bit encoder count.

This produces a map at 220 indicating the position of cut on as a function of angular position. Each map is unique to each filter.

The spectrophotometer which is used may have a maximum aperture of scanning that may be of a different size, usually smaller than, the scanning beam used for the final illumination. For example, the spectrophotometer may have an aperture of 5 mm, while the light beam may scan at 30 mm. Therefore, any individual scan may not be representative of the color that would be produced when the filter is used in a lighting fixture which has a much larger aperture, e.g. 30 mm. At 230, the map is compensated for the aperture mixing affect, essentially compensating for the larger aperture. The correction may be done by calculating an approximate weighted mean cut on for each of a plurality of smaller points in the map. Ideally, angular distances between scans of the filter will be an even fraction of the angle that the aperture occupies.

An area occupied by each scan in the aperture is first calculated. In the system used according to the preferred mode, the coating is radially measured. The aperture can be divided into radially divided segments centered on the center of rotation as shown in Figure 3. The center of rotation 300 is

used as a common point. A plurality of segments are formed. Each segment has an area $A_1, A_2 \dots A_n$, and a corresponding measured wavelength λ_1 , for segment a_1 and the like.

Once the area of each of the segments has been determined, the proportion that each segment occupies as compared with the total aperture area is next calculated.

$$\pi r^2 = \sum (A_1 \rightarrow A_7)$$

$$\text{Relative area } (a) = \frac{\text{segmented area}(A)}{\pi r^2}$$

The diagram of Figure 3 shows seven segments. Within each segment, there is a specified 50 percent cut on represented by λ . The weighted means of the segments is therefore

$$Wm = (a_1 \lambda_1) + (a_2 \lambda_2) + (a_3 \lambda_3) + (a_4 \lambda_4) + (a_5 \lambda_5) + (a_6 \lambda_6) + (a_7 \lambda_7)$$

or

$$Wm = \sum_{i=1}^7 (a_i \lambda_i)$$

This calculation may be repeated for each practical point on the map. That is, each aperture point may be characterized fully within the coated region of the filter.

By using this technique, most of the filter can be calibrated. The maximum calibrated region of the filter may be 360 degrees minus the angle occupied by the clear region in the angle occupied by one whole aperture. For example, for a 30 degree aperture and a 60 degree clear region, 270 degrees of the filter may be calibrated.

Once this has been completed, at 240, the map or look up table is distorted to show angular position as a function of cut on. This may be done by interpolation. A set of target values for each filter is determined. These may be, for example, ideal 50 percent cut on values. These target values may be evenly spaced within the 50 percent of the cut on range of the filter's characteristic. Alternatively, they may be tailored in order to increase resolution in certain areas of the filter. While both of these techniques will work, it may be essential that the same target values be used for every like filter, in order to make sure that the calibrated values look the same from each luminaire. The number of target values may be set to less than the number of values in the motor profiling table for a specified region.

The positions for these target values are then found by interpolation of the data in the distorted map. These positions are used for the calibration process. At 250, the motor module lookup table is re-profiled using this calibration data. Each motor, such as SM1, has an associated lookup table 131 along with servo motor drive electronics. The lookup table may include a specified number of positions, each position corresponding to a color. For example, there may be 49 positions. These 49 positions represent the start and end points of 48 line segments. These form a linear approximation

to occur from which the motor moves are profiled in the 270 degree calibrated region of the filter. The profile contains 49, 16-bit positions which extend from 8192 to 57344, and are linearly spaced at one K intervals. The motor profiling operation may move the motor to precise locations by interpolation between points on the table.

The positions of the target values may also be in the range of 8192-57344. These positions replace the linearly-spaced positions in the motor profiling table. This hence profiles the motor according to the filter map of weighted mean 50 percent cut on values.

Using this technique allows several fixtures to be sent the same color data by a controlling console. Each filter is moved to its unique position and outputs the same color.

Although only a few embodiments have been disclosed in detail above, other modifications are possible. For example, the system above has described one specific filter. It should be understood that other filters, including filters on which the gradient axis is linear or two-dimensional could similarly be characterized. The techniques given above of characterizing the radial filter can be extended to linear filters, and in many ways might be more simple in linear filters.

In addition, while this system has described distorting a lookup table in the servo drive electronics, other ways of using

this calibration data should also be understood. For example, the calibration data could be stored as the correction factor for use with existing electronics.

All such modifications are intended to be encompassed within the following claims, in which: